## International mitigation and adaptation strategies for climate change policy


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# 9 Summary and conclusions

## 9.1 Introduction and scope

Without additional policies, anthropogenic greenhouse gas emissions are likely to lead to an increase in global mean temperature of between 2.6 and 5.9°C during this century. The Fourth Assessment Report (IPCC, 2007d) indicates such a temperature increase bring serious risks to water supply, health, ecosystems, and food supply. To reduce these risks, policies could be implemented to reduce greenhouse gas emissions (mitigation) and to adapt to climate change (adaptation).

To assess the costs and benefits of climate mitigation and adaptation strategies over time Integrated Assessment Models (IAMs) have been developed. These models typically combine data from various disciplines to derive insights relevant to policy making. They are used to analyse long time horizons (often over 100 years) as input for short-term decision making.

IAMs cover the cause and effect chain in climate change, including:

- economic activities that cause emissions;
- effects of emissions on greenhouse gas concentrations in the atmosphere and ocean;
- changes in temperature and other parameters resulting from the increased concentrations and the impacts of these changes on ecosystems and the economy.

This study focuses on two important issues in the application of IAMs which are often paid too little attention to. Firstly, while cost-benefit IAMs often focus on an optimal pathway under default assumptions, climate change is beset with uncertainty. In this context, the effect of uncertainties on IAM outcomes needs to be explored. Secondly, most applications focus on assessing mitigation strategies with little attention to adaptation to climate change. This study investigates both of these issues in order to gain insights into what cost-benefit analysis can provide:

1. *into the optimum climate mitigation strategy and the robustness of such a strategy in view of various uncertainties and decision-making frameworks*
2. *about the relationship between adaptation and mitigation strategies*

The framework used to investigate these issues was the FAIR-CBA model, which is an extension of the FAIR model developed to assess the cost implications of emission allocation regimes. The FAIR-CBA model incorporates modules on climate change damage, adaptation costs, economic growth and discounting. These modules were developed for the research presented in this thesis.

## 9.2 Mitigation strategies

The effectiveness of cost-benefit analysis in assessing the optimum climate mitigation strategy and the robustness of such a strategy in view of various uncertainties and decision-making frameworks are presented in Chapters 2, 3 and 4. The effect of uncertainty and value judgements on the optimal mitigation strategy according to cost-benefit analyses are assessed in Chapter 2. The results of standard cost-benefit analyses are compared with an IAM-supported risk-based approach to climate change in Chapter 3. Finally, the consequences of different climate regimes on the costs and environmental effectiveness of greenhouse gas mitigation are discussed in Chapter 4.

***Chapter 2: Effect of uncertainty and value judgements on the optimal climate mitigation target***

The outcomes of cost-benefit analyses on climate change varied from support to very ambitious climate mitigation policy (stabilising greenhouse gas concentrations at 450-550 ppm $CO_2$ equivalents, as in Stern, 2006) to very modest emission reductions (stabilising greenhouse gas concentrations at 800-850 $CO_2$ equivalents, as recommended by Nordhaus, 2008). The FAIR-CBA model was used to systematically vary the main assumptions of a cost-benefit analysis on climate change over the range covered in the Stern and Nordhaus assumptions. The variables examined were climate sensitivity, damage estimates, mitigation cost estimates, time horizon of the analysis, discounting method, and baseline emissions. Instead of determining a single optimal emission pathway for each parameter setting, emission pathways leading to concentrations peaking at 500 to 800 ppm $CO_2$ equivalents were assessed. This enabled determination of the emission pathway with the lowest consumption loss due to mitigation and climate change damage, as well as assessment of the robustness of the preferred target.

The results show that the optimal $CO_2$ equivalent peaking concentration target from a cost-benefit analysis can range from very low values of 520 ppm to greater than 800 ppm. This wide range can be explained by differences in value judgements on the discounting method and time horizon, and uncertainties, particularly with regard to climate damage and mitigation costs. The analysis also showed that the differences between optimal and non-optimal cases are considerably lower than sometimes suggested when only an optimal concentration target is reported. In most cases, consumption loss is similar over a large range of concentration targets, indicating that factors other than those in the analysis (co-benefits, asymmetrical weighting of risks) may greatly influence the results.

Cost-benefit analysis is of value because it provides a systematic analysis of all costs and benefits in a formal framework. If done properly, this also includes a systematic consideration of uncertainty. However, because uncertainties and value judgements have such a strong impact on results, choosing long-term targets remains mostly within the realm of decision-makers and other societal actors, with only a supporting role for cost-benefit analysis.

### *Chapter 3: Preferred climate target according to a risk-based approach*

Cost-benefit analysis in determining a preferred climate policy has been criticised for its limitations in dealing with risks and uncertainty. As an alternative, the minimax criterion has been proposed which focuses on the potential risks of climate change, instead of the most likely outcome. This criterion requires minimising the maximum possible costs that society might face, and thus explicitly takes account of low-probability, high-impact events to the extent that such events can be assessed. As this approach has only been applied qualitatively for extreme policies, a quantitative comparison has been made of the results of a standard cost-benefit analysis with those from the minimax approach over a wide range of climate policies. This was done using the FAIR-CBA model.

Strict application of the minimax criterion (using the extreme value for each individual input parameter) in combination with a low or medium discount rate led to the conclusion that stringent greenhouse gas reduction policies should be implemented as soon as possible. The results are also very robust and the costs of not meeting the target are substantial. However, when a relatively high discount rate, such as suggested by Nordhaus (2008), is chosen, the minimax criterion does not lead to such far-reaching implications. Neither the preferred concentration level nor the robustness of the target was shown to differ substantially from that of a standard cost-benefit analysis. This implies that even when the minimax approach is used, the discount rate plays an important role.

***Chapter 4: Environmental effectiveness and economic consequences of different universal and fragmented climate regimes***

Most IAMs seem somewhat optimistic with regard to the participation of all major greenhouse gas emitting countries in a climate regime (universal regime). To assess the importance of this assumption, a literature review was carried out of the environmental and economic consequences of regimes in which full participation in a single international agreement is not achieved (fragmented regimes) compared with universal regimes. The feasibility of establishing a universal climate regime was also assessed.

There are numerous studies on the qualitative differences in climate regimes and on emission reductions resulting from these regimes. Fewer studies also consider the regional economic consequences. Those studies that do include cost analyses have used different tools including macro-economic models and energy models based on marginal costs curve approaches. Nevertheless, there is general agreement between these studies on which regions will experience high, medium and low costs under different regimes.

Quantitative assessments of climate regimes in terms of emission reductions and costs show that stabilising greenhouse gas concentrations at low levels is generally more costly under a fragmented regime. This is either because ambitious reduction targets have to be achieved by a smaller number of countries, or because emission reductions do not take place where it is cheapest to do so.

All studies also indicate that establishing a universal regime involves several challenges. For instance, in a universal regime based on a specific allocation rule, cost differences between regions are difficult to avoid. Even though costs are not the only consideration for participation in an agreement and certain equity principles could justify cost differences, reaching a universal agreement on climate policy is challenging because of large cost differences. In that context, the outcome of specific allocation rules will at best only serve as a starting point for negotiations. Furthermore, individual countries have an incentive to free-ride in a universal regime. This partly follows from the results of fragmented regimes, but even more clearly from game theory on coalition forming.

Game theory-based analysis shows that a stable regime with a high participation level is very unlikely to emerge, even though the likelihood can be increased by assuming alternative behaviour such as responsibility, or implementation of transfer schemes and exclusive membership.

Despite the difficulties in establishing a universal regime, some kind of transition from a fragmented to a universal regime seems to provide the best option for achieving large emission reductions. To simplify negotiations, a transitional and ambitious fragmented regime of the major emitting countries willing to agree to emission reduction targets could be established in the short-term. Such a coalition could provide the basis for a larger, universal regime in the long term.

## 9.3 Relations between adaptation and mitigation strategies

Chapters 5 to 8 focus on adaptation and mitigation strategies. An overview of how adaptation has been modelled in IAMs is given in Chapter 5, together with recommendations for improvements. The inter-linkages between adaptation and mitigation strategies from a cost-benefit perspective are presented in Chapter 6. An evaluation of burden-sharing regimes for greenhouse gas mitigation is presented in Chapter 7, taking account of both mitigation and adaptation costs and projected climate change damage. Finally in Chapter 8, an IAM is used to analyse the effectiveness of the current mechanism to finance adaptation in developing countries.

***Chapter 5: Improving adaptation modelling in IAMs***

Making adaptation costs more explicit in IAMs would improve the political salience of the model results. Yet, current IAMs give little explicit attention to adaptation. Because of various complications in assessing adaptation costs, it is likely that the few models that do explicitly incorporate adaptation may overestimate the level of adaptation and underestimate the cost. Given these crucial uncertainties, the representation of adaptation in IAMs needs to be improved, in particular by addressing specific characteristics of adaptation. These include the highly disaggregated nature of vulnerability and adaptive response; the importance of extreme events as triggers for adaptation; the scale dependence of adaptation; the role of non-market values; the non-optimal use of information by agents; and the central role of uncertainty in shaping private adaptation action.

Despite their current limitations, IAMs seem to be the most appropriate tool to assess how adaptation may interact with mitigation strategies, and especially how adaptation affects the level of mitigation. The initial results with the AD-DICE model suggest that adaptation strategies have a relatively limited effect on the optimal level of mitigation. However, if the total climate damage is higher than that used to calibrate models, adaptation strategies could have a much greater effect on a mitigation target.

***Chapter 6: Interactions between adaptation and mitigation strategies***

The FAIR-CBA model was used to analyse relationships between adaptation costs, mitigation costs and emissions trading, and residual damage. The method for modelling adaptation, known as AD-RICE, is based on the damage estimates in world regions according to the RICE model. While damage estimates are beset with uncertainty (see also Chapters 2 and 3), some of the qualitative conclusions derived from this assessment are robust.

Firstly, an important factor in comparing adaptation and mitigation is their totally different time dynamics. Adaptation can effectively reduce climate change damage in the shorter term but without mitigation, continued climate change implies that adaptation will not prevent the impacts worsening. Mitigation is very effective in reducing climate change damage in the long term. According to the FAIR-CBA model, the best results are obtained when both adaptation and mitigation are implemented.

Secondly, even though the costs of adaptation are currently assessed to be small compared to both the cost of residual damage and of mitigation, adaptation is important in reducing potential damage, especially in lower-income regions.

While the model results depend on very uncertain estimates of damage and adaptation costs, optimal adaptation efforts are projected to prevent more than a quarter of the potential damage by adaptation in the long term.

Thirdly, the optimal amount of adaptation in a region depends only in the longer term on the climate mitigation target. Without mitigation, climate change will be greater, thus increasing the need for adaptation. Regardless of the mitigation strategy, adaptation costs will increase substantially with time because climate will change even if emissions are drastically cut back. The model projections show that global adaptation costs increase from USD 10 billion in 2010 to USD 230 billion in 2050.

Fourthly, climate change costs differ substantially between world regions. For East Africa and South Asia, income losses are much higher than the global average and rise steeply for higher concentration targets. This indicates that both adaptation and mitigation are important especially for these developing regions.

Thus, adaptation will increase sharply over time even if strong mitigation measures are taken, and adaptation is especially important in developing regions. This indicates that the chances that developing countries join a climate mitigation regime could be higher if adaptation, and especially adaptation funding, is incorporated in the regime.

### *Chapter 7: Effectiveness of a 2% levy on CDM projects and emissions trading to finance adaptation in developing countries*

At the UNFCCC meeting in Bali in December 2007, introduction of a 2% levy on the CDM was proposed as a mean to finance adaptation costs in developing regions. It has also been proposed to extend the scope of the levy to emissions trading.

In this chapter, the results of application of the FAIR-CBA model to analyse the effectiveness of a 2% levy on both the CDM and emissions trading from developing countries are discussed. The analysis shows that the proportion of adaptation in developing countries that could be financed with a 2% levy depends on the global mitigation target. A more stringent target results in a higher value of emission rights being traded, which increases the revenue of a 2% levy. In the long term, a stringent target also reduces adaptation costs. All-in-all, with a 2°C target, about one-third of adaptation costs in developing countries could be financed by 2030 under our default assumptions on adaptation costs. This is only 15% under more pessimistic assumptions on adaptation costs. Under a less stringent target of 2.5°C, the proportion of adaptation that can be financed from a 2% levy decreases to 10–20%, depending on the emission allocation regime.

Although the revenues of a 2% levy are shown to be sensitive to the emission allocation regime and climate target, only a relatively small proportion of adaptation required in developing countries can be financed in this way in the coming two decades. Therefore, if the objective is to finance a considerable proportion of these costs through international funding, additional mechanisms are necessary. There are many proposals for additional funding mechanisms, but to date no systematic method has been established to analyse how much revenue these proposals would raise in the long term and the extent to which such funds would cover the adaptation costs. Further research using a similar approach as the current study may shed some light on this issue.

***Chapter 8: Including adaptation costs and climate change damages in evaluating burden-sharing regimes***

Many studies have evaluated the consequences of post-2012 emission allocation regimes on regional mitigation costs. The FAIR-CBA model has been used to evaluate not only mitigation costs, but also adaptation costs and climate change damage.

Adaptation costs and climate damage need to be included in evaluating burden-sharing regimes for two reasons. Firstly, including adaptation costs and damage gives a broader perspective in evaluating the fairness of climate policy. This is especially important for developing countries where impacts tend to be higher than the global average. Secondly, financing adaptation costs in developing countries has become an important issue in negotiations. Currently, this issue is discussed in parallel with mitigation but it might be useful to examine it from a more integrated perspective. This would, at least theoretically, allow an allocation regime to be designed that would lead to transfer of funds from developed to developing countries to finance adaptation.

The first general finding is that including costs other than mitigation costs gives a very different perspective on regional costs. For several climate regimes, such as contraction-and-convergence and multi-stage, mitigation costs are low or negative for developing regions, as a result of less ambitious targets and emission trading. However, the greatest damage and adaptation costs are projected to occur in developing countries. The total costs for these countries are considerably higher than suggested on the basis of mitigation costs alone. This becomes increasingly important over time. Up to 2050, the revenues from emission trading may be large enough to compensate for both adaptation costs and residual damage in the least developed regions, provided that climate policy limits climate change to 2°C. However, by 2100, these regions are expected to experience the highest overall costs under all burden-sharing regimes considered, even with a 2°C target.

The distribution of the total costs might be a reason to allow for emission trading between regions in order to compensate for the higher adaptation costs and residual damage. Allocation regimes based on mitigation-focused equity principles, such as common but differentiated responsibilities, can lead to transfer of funds from developed to developing countries to compensate for adaptation costs and climate change damage, at least for the next few decades. An essential condition is that a global emission trading scheme is implemented so that developing countries can sell their allocated excess emission permits.

Finally, the cost differences between the regimes are considerable in the short to medium term, but they all converge in the long term. The reason is that by then climate change damage is too great in developing regions to be compensated by allocation-based burden-sharing regimes.

## 9.4 Conclusions and steps ahead

### 9.4.1 Main conclusions

IAMs are an effective tool to systematically analyse the costs and benefits of climate change policy in a formal framework. However, cost-benefit analysis is unlikely to give decision-makers a single, clear answer about the optimal climate target. This is mainly due to the sensitivity of value judgements on the results – the most important of which are the discounting method and valuation of climate change impacts.

Use of cost-benefit analysis to inform policy-makers about the best climate target has been criticised for other reasons, notably their inability to take sufficient account of low-probability, high-impact events. As an alternative to cost-benefit analyses, the minimax criterion has been proposed for climate policy recommendations. This criterion aims at minimising the maximum possible loss to society.

Application of the minimax criterion in an IAM has been shown to lead to more stringent and more robust climate mitigation recommendations (stabilisation of greenhouse gas concentrations at around 450 ppm $CO_2$ equivalents) compared to cost-benefit analyses, but only for low to medium discount rates. For relatively high discount rates (similar to the market interest rate), the outcomes of the minimax criterion do not vary substantially from cost-benefit analyses. So in the end, the importance society attaches to the welfare of future generations critically influences the preferred mitigation target. Thus under the condition that the current generation accepts welfare losses to the benefit of future generations, a greenhouse gas concentration target of 450 ppm $CO_2$ equivalents can easily be justified. However, to meet such a target, all major greenhouse gas emitting economies must participate in a global climate agreement in the coming decades.

Adaptation and mitigation cannot be regarded as substitutes for one another. Adaptation can effectively reduce climate change damage in the short term but is much less effective in the long run because it does not reduce climate change itself. Mitigation is very effective in reducing climate change damage in the long term. Investment in adaptation measures seems especially important in low-income regions such as Sub-Saharan Africa and South Asia where income losses due to climate change are expected to be much higher than the global average, especially for higher concentration targets.

However, since adaptation can only limit climate change damage to a certain extent, mitigation is also necessary in these developing regions. In order to help developing countries to finance adaptation measures, the Adaptation Fund has been established. However, the revenues of the current funding mechanism – a 2% share of proceeds from projects under the Clean Development Mechanism – is much too small to substantially finance adaptation in developing countries. This is the case even when the 2% share of proceeds is broadened to include emissions trading. To provide adequate funds, additional financing mechanisms are required. Another way to transfer funds from high-income to low-income countries is to allow emission trading between these regions. If low-income countries join a climate agreement with certain emission allocation regimes based on mitigation-focused equity principles, this can lead to substantial transfer of funds from high-income to low-income countries. This requires both an ambitious climate target and implementation of a global emission trading scheme so that low-income countries can sell their allocated excess emission permits.

### 9.4.2 Steps ahead

Recommendations for future work relate to model analysis and model development.

Regarding model analysis, the conclusions of Chapter 7 – the inadequacy of the current mechanism to finance adaptation costs – indicate that other financing mechanisms are necessary. This is underscored in the Copenhagen Accord, which includes the passage that "developed countries commit to a goal of mobilizing jointly USD 100 billion dollars a year by 2020 to address the needs of developing countries".

Several proposals have been made to increase the international financing for developing countries (for an overview, see Müller, 2008). For some of these proposals, the amount of funding generated and distribution of the burden across countries depend on the level of mitigation (via the international permit price) and the emission allocation regime (via the level of emissions trading). Interesting future research, therefore, is how much funding the various financing mechanisms will generate and who will pay, under different assumptions on the level of mitigation and emission allocation regime.

With regard to model development, the level of detail of modelling mitigation is much higher than modeling impacts and adaptation. Mitigation costs especially in most policy evaluation IAMs are based on detailed energy models, whereas the mitigation benefits (impacts on climate change) and adaptation costs are generally depicted by a few equations that are calibrated using general assumptions.

The way forward may be to link IAMs that measure physical impacts with cost-benefit IAMs. The cost-benefit IAM could then be used to monetise the physical impacts, which is already done implicitly in current cost-benefit IAMs. This method will have several advantages.

This method would provide a better foundation for impact estimates. Currently, most damage estimates are based on work done by Nordhaus and Boyer (2000) and Tol (2002a; 2002b). These scientists base their damage estimates on statistical relationships between temperature and impacts by sector (for instance, health, agriculture, or settlements). For most world regions, however, these relationships are not available and thus "expert opinion" is therefore necessary. Linking the damage estimates to IAMs with detailed modelling of physical impacts seems an improvement on current practice of estimating damage.

This proposed method would also provide more sectoral and regional detail of the impacts needed in assessing adaptation needs because this depends on the expected climate impact on specific sectors and regions. It allows a sensitivity analysis on sectoral and regional level, and on the method of monetisation. The current damage functions applied in cost-benefit IAMs are aggregated functions for the world or for world regions except for the FUND model (Tol, 2002c) where total damage is the sum of all sectoral damage. A sensitivity analysis for a specific sector is therefore currently not possible within the IAM, with the exception of FUND.

Such a sensitivity analysis could be of vital importance, since the impacts of climate change on agriculture could be more uncertain for India than for Western Europe, for instance. The importance of monetisation can be shown using health as an example. In the DICE model, a year of life lost due to climate change is valued at twice the per capita income (Nordhaus and Boyer, 2000). In the FUND model, a life lost is valued at 200 times the per capita income (Tol, 2002a). Even though FUND values a whole life lost, and DICE values a year of life lost, this difference has an enormous effect on the projected health damages.

The above shows that there are important advantages in linking IAMs that measure impacts in physical units with cost-benefit IAMs. However, linking these two types of models is not easy. Cost-benefit optimisation IAMs need to be relatively simple for the optimisation process. A hard link between these two types of models therefore seems impossible to achieve. A model of the type used for this thesis does not require an optimisation process and may be more suitable for linking with a physical impact IAM. Another difficulty is that most IAMs measuring impacts in physical units have less coverage in the range of impacts than cost-benefit IAMs. The DICE model, for instance, includes sectors such as "non-market time use" and "catastrophic impacts". For such types of impacts, it does not seem fruitful to link with physical impact IAMs. For impact categories such as health and agriculture, however, linking cost-benefit IAMs with IAMs measuring impacts in physical units could improve both damage and adaptation needs estimates.